QUALITATIVE LEVEL OF SERVICE ANALYSIS OF URBAN STREETS IN INDIAN CONTEXT

Master of Technology

In

Transportation Engineering

By

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ODISHA - 769008

2015

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Under the guidance of

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CERTIFICATE

This is to certify that the thesis entitled, "**Qualitative level of service analysis of urban streets in Indian context**" submitted by **Atmakuri Priyanka** in partial fulfilment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Transportation Engineering** at the National Institute of Technology Rourkela for the academic year 2013-2015 is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENT

First and foremost, I offer my sincere gratitude and respect to my project supervisor, Dr. P.K. Bhuyan, Professor of the Civil Engineering Department, for his invaluable guidance and suggestions during my study. I consider myself extremely fortunate to have had the opportunity of associating myself with him for one year. This thesis was made possible by his patience and persistence.

I am very thankful to Dr. S. Sarangi, Director, Dr. S.K. Sahu, HOD of Civil Engineering Department, Dr. Mahabir Panda, and Dr. U. Chattraj, for their helpful suggestions during my entire course work. I also extend my sincere thanks to the Department of Civil Engineering.

I also want to convey sincere thanks to all my friends, especially Shweta Rao, Ch. Haritha, Yadu Krishna, Suprava Jena and Krishna Gupta for their help and support throughout my project. I would also like to present my gratitude to my colleagues for making my stay in the campus a pleasant one.

Last but not the least, I would like to express my heart-felt gratitude to my parents, my family and my well-wishers for giving me strength and courage always.

Atmakuri Priyanka

ABSTRACT

Level of service (LOS) methodology incorporating user perceptions provides a tool to describe how well a transportation facility satisfies their road users. India being a developing country, the traffic especially in urban streets is highly heterogeneous consisting of various kind of vehicles having different operational characteristics and a complex interaction between them. There are several engineering factors other than average speed and density that affect drivers perceptions for service quality. As LOS is not well defined for highly heterogeneous traffic flow condition on urban corridors in India, an attempt has been made to represent variability and complexity of human perceptions.

About 250 responses of road users have been collected from three mid-sized cities of India, i.e. Rourkela, Vishakhapatnam, and Trivandrum, which can be characterized by different types of road geometrics and operational conditions. A questionnaire has been prepared considering various factors that affecting the quality of service, which were grouped into eight factors using factor analysis. A regression model was developed taking these eight factors as predictors and overall satisfaction as dependent variable. Ranges of LOS scores was obtained by K-means clustering. Further, Fuzzy logic method in which fuzzification of input parameters, generation of fuzzy rules, and Defuzzification of output has been applied. The result show the model is reliable and has a good correlation coefficient (R^2 = 0.71). LOS categories obtained from the regression and fuzzy logic models were compared with perceived LOS, and were found to be almost similar indicating the effectiveness of the models. Only gender had statistically significant effect on the subject's ratings of overall satisfaction.

Key Words: LOS, user perceptions, multiple regression, fuzzy logic, clustering.

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LIST OF ABBREVIATIONS

A	Aesthetics
AO	Arterial Operations
HCM	Highway Capacity Manual
HFIS	Hierarchical Fuzzy Inference System
IO	Intersection Operations
LOS	Level of Service
M	Maintenance
OF	Other Facilities
OS	Overall Satisfaction
QOS	Quality of Service
RB	Road user behaviour
RD	Cross-section of Roadway Design
SM	Signs and Markings
SPSS	Statistical Package for the Social Sciences
TF	Traffic Facilities
TO	Traffic Operations
TRB	Transportation Research Board

CHAPTER 1

INTRODUCTION

1.1 General

Highway Capacity Manual (TRB, 1965) first introduced the concept of level of service (LOS). HCM, 2000 defined Level-of-Service as "a quality measure describing operational conditions within a traffic stream, generally in terms of service measures such as speed and travel time, freedom to manoeuvre, traffic interruptions, and comfort and convenience." Later HCM 2010, modified the LOS definition by incorporating traveller perspective view. HCM, 2010 definition of Level-of-Service is further improvised as "a quantitative stratification of a performance measure or measures that represent quality of service." Quality of service describes how well a transportation facility or service operates from the traveller's perspective. For each service measure the HCM defines six categories of level of service, ranging from A to F. LOS A is the best and LOS F is the worst.

India being a developing country the traffic is very much heterogeneous consisting of various kinds of vehicles having different operational characteristics. There is an exponential increase in growth of traffic with an increase in population. India is facing a lot of problems like haphazard traffic growth and congestions in traffic streams. The motorized mode of transport outnumbers the non-motorized mode. Growth in this motorization leads to a dramatic increase in the number of accidents and air pollution. In order to minimize all these problems, a proper traffic management should be needed.

There are several road transportation infrastructures in terms of facility and mode like private and public mode. Our observations touches every sphere of transportation and all the road users irrespective of mode of travel, gender and age group (>18yrs) are taken into consideration because the satisfaction levels varies from person to person. Human perceptions are vague and are in linguistic terms. Hence, Fuzzy sets can be used to evaluate these linguistic based problems.

1.2 Problem Statement

In general, most common factors considered for evaluating LOS consists mainly of delay, pavement quality, safety, etc. These factors contribute to quantitative estimation of service quality. But the users' opinion about the various transportation facilities and their operating conditions is neglected in this aspect. In India, many researchers worked on this quantitative approach which could not represent the variability and complexity of human perceptions as they didn't take users perceptions into consideration.

Many researchers from countries like Malaysia, China, and USA etc. used the perception data to evaluate level of service. But in India, this kind of research work taking all the qualitative measures of road transport into account has not yet come into limelight. Hence, in present scenario, to evaluate level of service based on road users' perception, no proper methodology is there. So, it is needed to develop suitable methodologies for level of service analysis of urban streets based on users' perception for different modes of transport.

1.3 Objectives

The objectives of this study are:

1. To identify the factors that affects road users' perceptions on quality of service.

2. To develop suitable methodologies to determine users' opinions regarding roadway quality of service.
3. To define various categories of LOS boundaries by using an appropriate classification technique.
4. To compare and validate the developed methodologies.

1.4 Organization of Report

This report consists of six chapters.

The first chapter gives an introduction of the research work, problem statement and objectives of this study.

Second chapter discusses about various literatures related to road users perception, various methods like factor analysis, regression techniques, fuzzy based techniques and discrete choice techniques.

Third chapter gives a detailed description of procedures of various methods.

Fourth chapter presents study area and data collection of the present study.

Fifth chapter comprises of the analysis of data and the obtained results.

Sixth chapter gives summary and conclusions. Future scope of the study is also discussed in this chapter.

CHAPTER-2

LITERATURE REVIEW

2.1 General

This chapter focuses on users' perceptions of quality of service on urban streets, rural roads and signalized intersections. The pedestrian LOS, motorcycle LOS, bicycle LOS which takes into account the users perceptions are also presented. Various methods that researchers have followed to evaluate LOS based on users perceptions are discussed in this chapter.

2.2 User Perceptions based LOS

Pecheux (2003) studied on the Quality of Service(QOS) of urban arterials taking into consideration of drivers perception. Data was collected using in-vehicle approach method and also by collection of written surveys in which participants give their perception of the drive based on roadway, environmental and operational conditions on urban arterials. This study produced a inventory of about 45 driver identified QOS factors which fall into a group of eight investment areas.

Ibrahim (2003) investigated non-car owners and car owners' perceptions towards different transport modes for shopping purposes. Attitudinal data is served as explanatory variables in mode choice models. They adopted both qualitative and quantitative researches. The results from the qualitative research found that shoppers perceptions on different transport modes for shopping purposes are affected by travelling attributes and socio-economic structure of the shoppers. In the quantitative research shoppers were asked to rate different transport modes for shopping purposes based on several variables. They found that each transport mode has its own unique set of attributes.

Hummer et al. (2005) developed model to evaluate level of service on shared use paths. From 10 paths about 36 video clips were shown to volunteers and they were asked to rate the path based on the four facility conditions on a five point scale. A model is developed relating the perceptions to operational and geometric variables. The results from the model reveals that there is a strong relationship between the path operations related variables and the overall perception of the quality. This model follows the existing HCM LOS method.

Araujo and Braga (2008) adapted a methodology for the qualitative LOS evaluation of pedestrian crossings at road junctions with traffic lights. Seventeen technical specialists were participated in the selection of the performance measures (Comfort, Safety, System Continuity), with their respective attributes. Participants were asked to rate the pedestrians satisfaction level in accordance with the attributes. Psychometric methods were used for evaluating the users' perception of the subjects based on Paired Comparison and Constant Sum. For the pedestrian facility, Khisty's methodology was adopted to relate the level of satisfaction with a qualitative LOS.

2.3 Methods for Evaluating Perception based LOS

2.3.1 Fuzzy sets

Fang et al. (2003) implemented a methodology to define level of service boundaries at signalised intersections based on users perception using fuzzy clustering technique. Captured video clips of 24 signalized intersections were shown to 100 subjects and were asked to rate the intersection. The six categories of service in terms of drivers time estimating capabilities are distinguished in the fuzzy domain. Based on the results of fuzzy clustering each estimated delay is classified into one primary and one secondary LOS category.

Lee et al. (2005) evaluated quality of service of Variable Message Signs (VMS) with the fuzzy approach. Survey technique, videobased experiments, and in-vehicle field methods are used to collect the user perceptions. Two membership functions are constructed with interval estimation and pairwise comparison methods. Fuzzy weighted average technique is used on the 322 perceptions data. The final defuzzified value gives the degree of satisfaction level with VMS.

Chen et al. (2009) provided an alternative methodology to predict road user perceptions of signalized intersection LOS on the basis of fuzzy neural networks. Videos were shown to the participants and were asked to rate the intersection based on the turning movements. Turning movement LOS model is developed, calibrated and validated with the help of the visualization based survey data.

Zhang and Prevedouros (2011) presented a methodology using fuzzy logic to determine the signalised intersection level of service considering the road user perceptions. They collected perception data by conducting web based survey. About 1300 responders found that Left turn (LT) treatment, delay and pavement markings are the most important factors influencing the signalized intersection LOS. Those three input factors are used in generating fuzzy rules and a composite LOS is measured.

2.3.2 Regression techniques

Petritsch et al. (2006) developed a field-calibrated pedestrian level-of-service (LOS) model that represents pedestrians perceptions of how well urban arterials meet their needs. About 500 participants were presented a scoreboard in which they were asked to rate the facility that serves the needs as a pedestrian. Data was analyzed using the stepwise regression modelling in which traffic volume on the adjacent roadway and density of conflict points along the facility are taken as primary factors.

Papadimitriou et al. (2010) identifies and analyses the perceived highway level of service with respect to personal attributes of road users like driver's age, driving experience, gender, familiarity of the road with respect to traffic conditions like vehicle capacity and volume to capacity ratio. They carried a field survey in which 264 subjects were taken a short interview and were asked to rate assess the traffic conditions in a scale from 1 to 10. The relationship between level of service which is perceived and traffic condition is analysed by means of a linear regression technique for different scenarios in terms of the number of levels of service.

2.3.3 Factor analysis

Joewono and Kubota (2007) aimed in improving the ridership quality in the existing paratransit system. They collected about 980 user perception data relating to quality of service, overall satisfaction and loyalty in using the paratransit system. Factor analysis is carried on the data and about eight factors with 35 attributes were extracted. The results of confirmatory factor analysis and the model reveals that in future paratransit is able to satisfy needs that was created by excess of passenger trips of private mode over road transport.

Musicant (2011) focused on measuring the company car driver aberrant behaviours, safety climate and safety attitudes perceptions. For this they collected the attitudes of 110 company car drivers by preparing a 34-item questionnaire. Factor analysis is performed on the collected data and it yielded six factors. Three subgroups were identified in the K-means clustering technique procedure. The results shows that the characteristics of the different subgroups of company car drivers can help in understanding the safety counter measures.

Freeman et al. (2009) examined the driving behaviours in an Australian fleet with the help of the Manchester Driver Behaviour Questionnaire (DBQ). About 4792 professional drivers completed the survey by indicating their response on a six point scale. Factor analysis is carried on the DBQ data and it revealed a three factor solution. They employed two logistic regressions for the traditional and the present DBQ factors. The results revealed that the number of km driven by the participants gives a indication of predicting the crash involvement.

CHAPTER-3

METHODOLOGY

3.1 General

From the literature, it was found that to evaluate LOS, other than quantitative methods there are several methodological approaches to evaluate the LOS based on users' perceptions. This chapter discusses about some of the methodological approaches that had been applied to relate road user perceptions and LOS are factor analysis, regression-based method and fuzzy set based method-fuzzy logic/fuzzy inference method. Clustering technique to define LOS boundaries is also presented in this chapter.

3.2 Factor Analysis

The purpose of the factor analysis is that it will reduce large set of data to a smaller subsets of measurement variables. Factor analysis has the following uses: (1) to understand the structure of set of variables; (2) construction of a questionnaire to measure a variable that is underlying; (3) reducing the data set into a manageable size while retaining much of the information as possible.

The 33 statements in questionnaire captures information on different aspects of transportation system. There are two reasons for not using all these 33 statements as variables in the choice model. First reason is that there will be a high degree of correlation in between these statements and second is that using 33 variables is not desirable from the view standpoint of parsimony of the model. The captured information of the 33 statements is condensed into manageable as well as uncorrelated variables set by adopting factor analysis methodology. The ratings on the 33 statements are produced by underlying and unobserved attitude is the assumption made by the factor analysis.

3.3 Regression Technique

From the factor analysis eight factors has been extracted. The statement scores under each factor is summed up and a mean value is taken for each person. The eight factors mean values are taken as independent variables. Overall satisfaction score for the city of each individual is taken as dependent variable. A model is developed by multiple regression technique. Multiple regression analysis is a way of predicting dependent variable from several independent variables.

Each dependent variable has their own coefficient and the independent variable is predicted from combination of all variables multiplied with their respective coefficients plus error term as shown in the equation 3.2.

$$Y_i = b_0 + b_1X_1 + b_2X_2 + ... + b_nX_n + \varepsilon_i \quad \text{for } i = 1,2, ... n. \qquad - (3.2)$$

Where, Y is dependent variable, b_1 is coefficient of first independent variable (X_1), b_2 is coefficient of second independent variable (X_2), b_n is coefficient of nth independent variable (X_n) and ε_i is error term.

80% of the data is used for analysis in regression and remaining 20% of the data is used for validation.

3.4 *K*-means Clustering

K-means is one of the algorithms to solve clustering problem. A *k*-means cluster analysis on a data set initially clusters the data based on K points representing group clusters. Then, each objects gets assigned to group with closest centroid and then the same procedure is repeated by calculating K centroids until there is no change in centroids.

After regression equation is developed, the outcome OS scores are clustered by using k-means clustering technique. This method of clustering has been adopted to distribute ranges for level of service (LOS). The strength of this clustering was decided based on the Silhouette value.

3.5 Fuzzy Logic Method

L. A. Zadeh was the first to introduce the concept of fuzzy sets in 1965. This concept is used in many areas related to human perception. Perception based information is in the form of linguistic terms and this can be easily operated by fuzzy sets. Various applications of fuzzy set are fuzzy techniques are fuzzy inference system, fuzzy aggregation method, fuzzy regression, and fuzzy clustering. Fuzzy inference system has been applied in the present study.

Fuzzy logic, also called as fuzzy inference system is one of the most commonly used fuzzy technique. Fuzzy inference is deductive process of formulating from input to an output by using fuzzy logic. Human decisions give ambiguous information which are represented through linguistic terms. The method of reasoning with linguistic terms using fuzzy set theory is fuzzy inference system. The methodology of fuzzy logic analysis is outlined in figure 3.1. It consists of three parts: fuzzification, fuzzy inference and defuzzification.

3.5.1 Fuzzification: The input data are crisp values and so they need to be converted into fuzzy sets. Figure 3.2 shows the fuzzy sets for the input variable. Triangular membership functions are used popularly and extensively in fuzzy set applications due to simple formulas and efficiency in computation. Therefore, triangular fuzzy membership functions are considered in this study. Triangular function consists of three parameters. These parameters control exact shape of membership function and their function values. Equation (3.3) shows the triangle function equation.

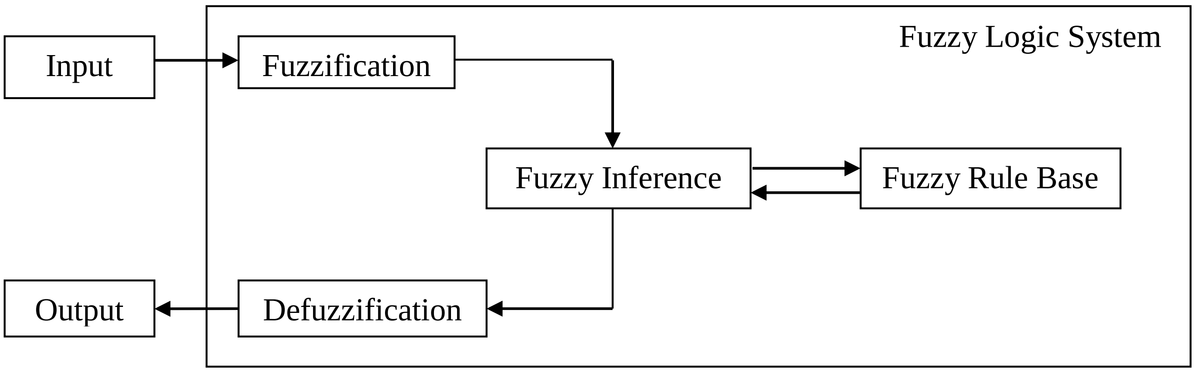

Figure 3.1 Structure of fuzzy logic system

$$\textit{Triangle } f(x,a,b,c) = \begin{bmatrix} 0 & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & c \le x \end{bmatrix} \qquad \text{- (3.3)}$$

All the input variables are classified into three groups: good, fair and poor. Fuzzy set for output variable LOS rating is shown in fig.3.3. The output variable is classified into six groups to be consistent with HCM 2000. Each group is assigned by a linguistic term (e.g., very good, acceptable, poor) with a letter grade A to F. The fuzzy set of LOS is based on numbers from 1 to 6, whereas 1 represents the best and 6 represents the worst.

Table 3.1 Parameters of triangular fuzzy membership function for roadway design

Group name	A	b	C
Good	1	1	4.3
Fair	1	4.3	7
Poor	4.3	7	7

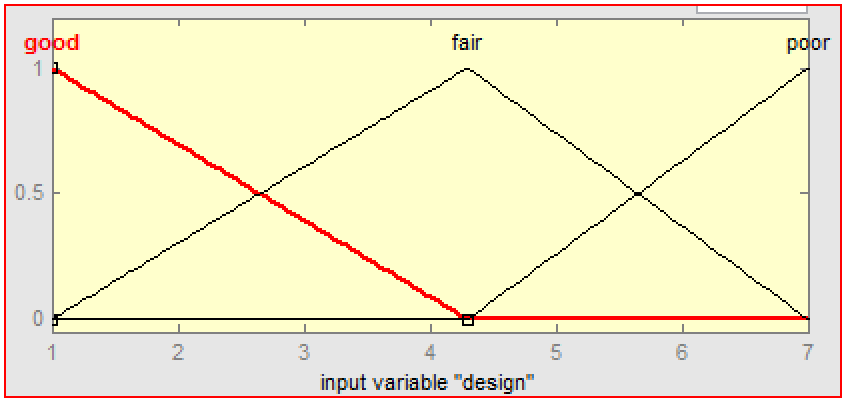

Figure 3.2 Triangular fuzzy membership function for roadway design

3.5.2 Fuzzy inference: After the fuzzification of input variables, the resulting fuzzy rules are entered in the fuzzy inference system. Fuzzy inference system is based on the generation of a set of "If-Then" fuzzy rules.

The general format of fuzzy rule is as follows:

If {RD is X_{RD}} and {TO is X_{TO}} and {TF is X_{TF}} and {RB is X_{RB}}, Then {LOS is Y}

Where, RD = Roadway Design

X_{RD} = fuzzy set for roadway design, i.e., good, fair, poor

TO = Traffic Operations

X_{TO} = fuzzy set for traffic operations, i.e., good, fair, poor

TF = Traffic Facilities

X_{TF} = fuzzy set for traffic facilities, i.e., good, fair, poor

RB = Road user Behaviour

X_{RB} = fuzzy set for road user behaviour, i.e., good, fair, poor

Y = fuzzy set for LOS, i.e., very good(A), good(B), fair(C), acceptable(D), poor(E), very poor(F)

Generation of fuzzy rules increases with the increase in input variables and the number of descriptors in each membership function. This is termed as "rule explosion problem." In the present study there are eight input variables and each input variable has three descriptors namely, good, fair, poor. So about 3^8=6561 fuzzy rules are to be generated and is a cumbersome process. Hierarchical fuzzy inference system is one of method to solve the "rule explosion problem." Hierarchical fuzzy system is proposed by Roju, Zhou and Kisner in 1991 to reduce the computational complexity of a multivariable fuzzy system and the number of fuzzy rules.

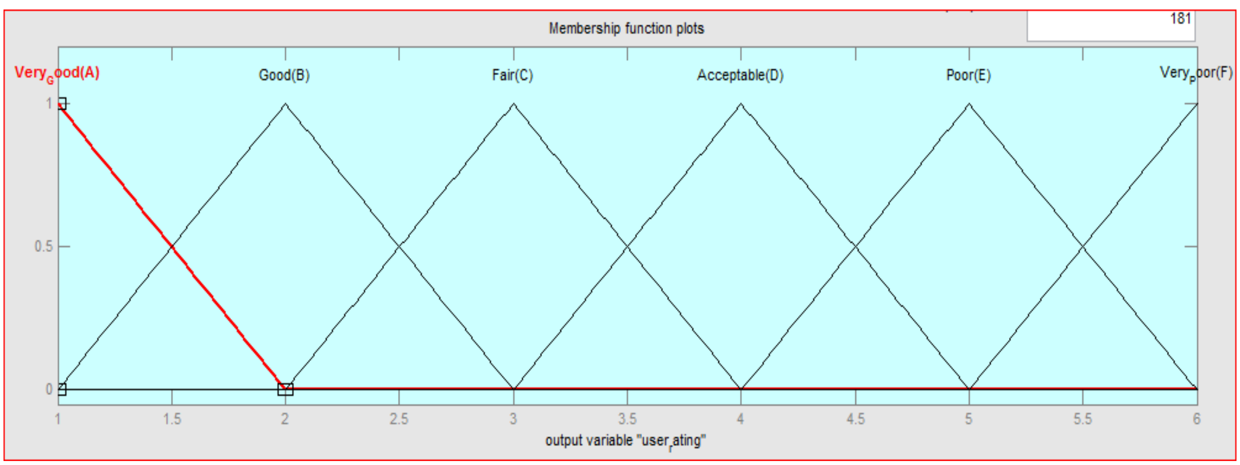

Figure 3.3 Fuzzy membership function for the output variable LOS rating

To build the two levels of fuzzy inference system, Mamdani inference system is used in which "max-min inference" has been employed. Fuzzy toolbox in MATLAB release R2012a is used in building these fuzzy inference systems.

3.5.3 Defuzzification: Defuzzification is the last step in the fuzzy logic in which only one value is chosen for the output variable. Centre of gravity also known as Centroid method is the commonly used defuzzification strategy for continuous membership functions. It can be calculated as follows:

$$CG(A) = \frac{\int u_A(x).x\ dx}{\int u_A(x)\ dx} \qquad - (3.4)$$

Grades of membership function are used to assign the confidence. For a specific LOS, confidence level can be determined as follows:

$$CL_{LOS_j} = \left\{\frac{MG_j}{\sum MG_j}\right\} * 100\% \qquad - (3.5)$$

Where,

LOS_j = j^{th} LOS category (A-F)

CL_{LOS_j}= confidence level that LOS follows j^{th} LOS category

MG_j = membership grade of j^{th} LOS category

3.6 Statistical Analysis

χ^2 - tests were applied for dependent variables with nominal-level data. Kruskal- Wallis One- way ANOVA was applied for dependent variables with ordinal level data to assess whether there are significant differences among different independent groups. Mann- Whitney test was further used to conduct pairwise comparisons for significant independent variables. The 0.05 significance level (i.e., 95% confidence level) was used in the statistical analysis.

CHAPTER 4

STUDY AREA AND DATA COLLECTION

4.1 General

To develop a best model which suits for all traffic conditions, responses from different states possessing different types of road conditions and different volumes of pedestrians, bicycles, motorists and other heavy vehicles have to be collected. Hence, in this aspect responses of road users irrespective of age and gender have been collected from different cities of India like Rourkela of Odisha state, Visakhapatnam of Andhra Pradesh state, and Trivandrum of Kerala state.

4.2 Study Area

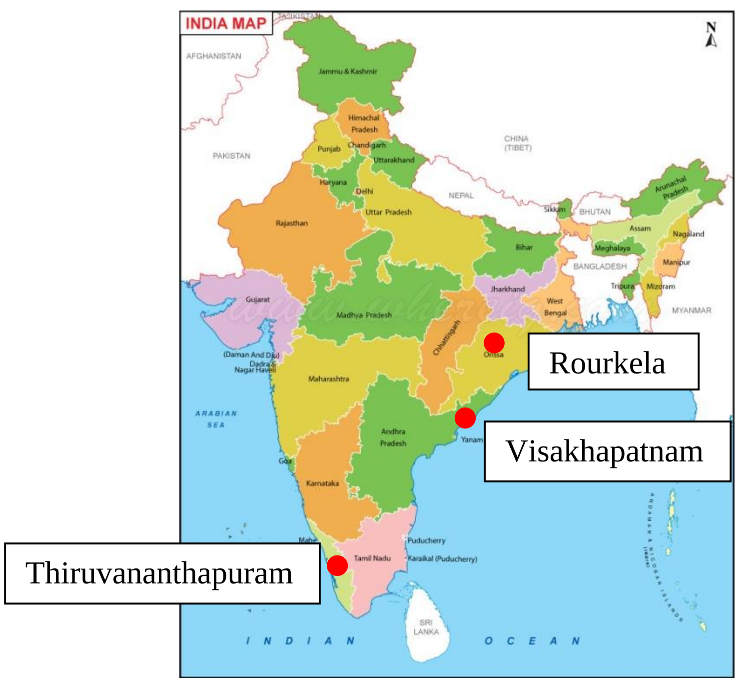

Figure 4.1 Map showing the data collection cities

4.2.1 Visakhapatnam

Visakhapatnam is a major city of Andhra Pradesh state which is ranked to be the 17th most populous city in India. It is the largest city having an area of 681.96 km^2. One of the major seaport is in Visakhapatnam. There are more males than the females. The road network is connected with NH5.

Figure 4.2 Study area and different site locations in Visakhapatnam

4.2.2 Rourkela

Rourkela is one of the largest city in Odisha state. It is known for its educational activities and steel plant. It is a planned city with broad road network. The city is connected with NH-23 and SH-10. There are more males and females.

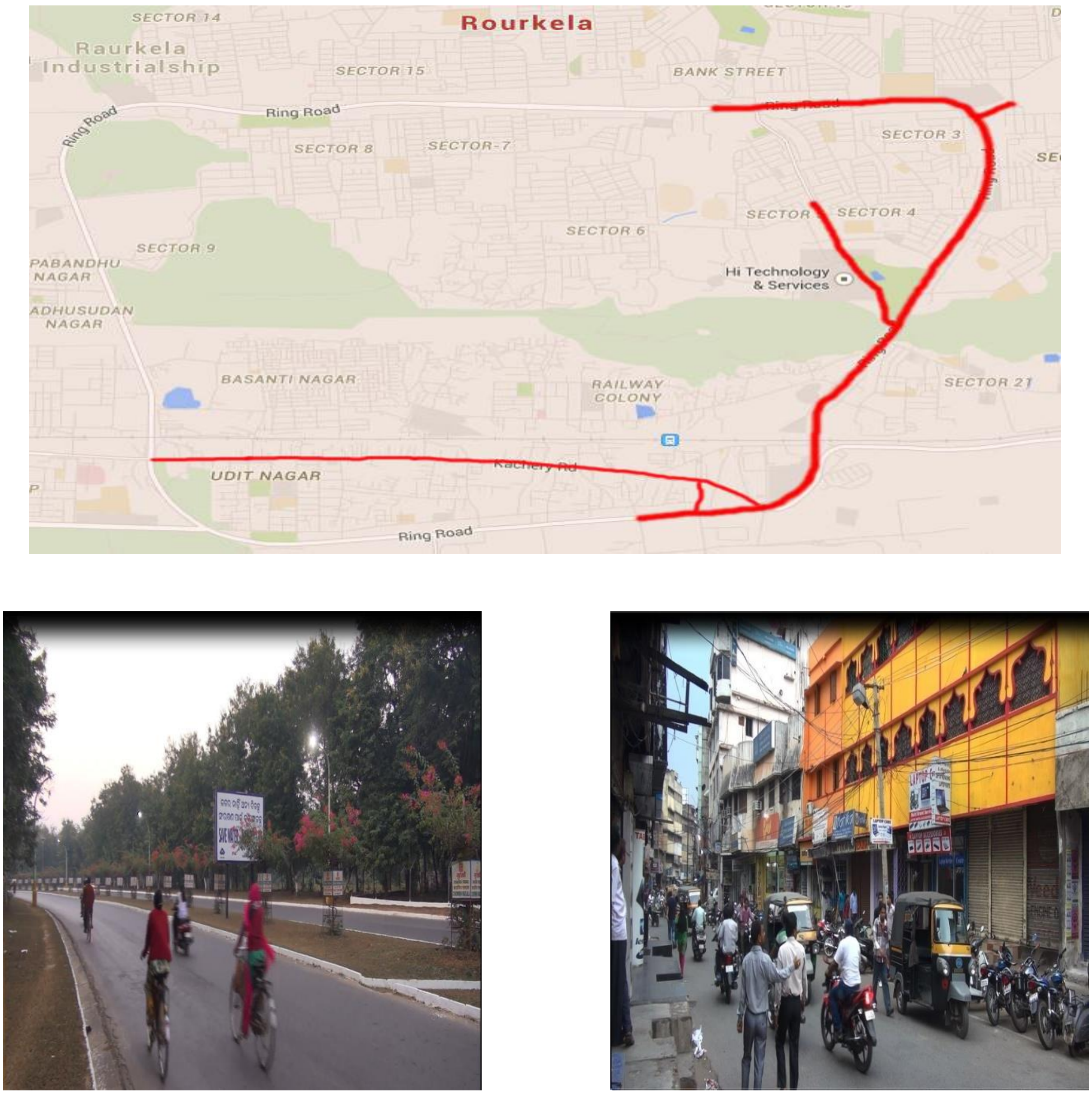

Figure 4.3 Study area and different site locations in Rourkela

4.2.3 Thiruvananthapuram

Thiruvananthapuam is also known as Trivandrum and is the capital of Kerala state. It is the fifth urban agglomeration city in Kerala. There are more females than males. Road network is connected with NH-66 and SH-1. IT companies and small scale industries are there in Trivandrum.

Figure 4.4 Study area and different site locations in Thiruvananthapuram

4.3 Data Collection

There are various quality of service factors affecting the road users satisfaction levels on various transpiration facilities. A questionnaire based on those quality of service factors is prepared. These satisfaction levels largely varies from person to person. So in this study perceptions of all the road users irrespective of gender, age group and road transport travel mode has been collected.

From the literature it is found that there are various methods to collect the user perceptions of satisfaction. These methods include traveller intercept surveys, video laboratory studies and field laboratory studies.

Representation of wider driving population, collection of relatively large sample size and cost effective method regarding the sample size are the strengths of the traveller intercept survey.

In this study, data was collected using traveller intercept surveys. Survey was conducted at residential and commercial areas in all the three cities. The survey included personal information such as gender, age and driving experience. Questionnaire includes about 35 questions based on various QOS factors. In the survey about 250 subjects from the three cities were interviewed and were asked to rate their perception of satisfaction on a scale ranging from 1 to 7.

4.3.1 Demographic analysis:

Satisfaction level on different transportation facilities varies from person to person. So in this study, responses were collected from the participants of both gender and different age groups. Driving experience (in years) of the participants was also collected. Table 4.1 shows the demographic analysis of the collected data. About 250 responses has been collected from all the three cities in which each city contributes about 33% of the total data.

Table 4.1 Demographic analysis of collected data

Variable	Description	Total Data	
		Frequency	Percentage (%)
Gender	Male	170	68
	Female	80	32
Age	20-30	178	71.2
	31-40	30	12
	41-50	24	9.6
	51-60	18	7.2
Driving experience (in years)	0-5	131	52.4
	6-20	103	41.2
	>20	16	6.4

CHAPTER 5

RESULTS AND ANALYSIS

5.1 General

The collected data was analysed by means of factor analysis. Two models were developed and ranges of LOS categories were given using clustering technique. All these aspects were discussed in this chapter. Results, comparison and validation of the models are also presented in this chapter.

5.2 Factor Analysis

As a part of survey, respondents has been asked to state their agreement and disagreement level with 33 statements relating to various quality of service factors of transportation system. Each of these statements was rated on seven-point Likert scale from 'strongly disagree (1)' to 'strongly agree (7)'. Collected data has been analyzed using SPSS software. A principal component analysis was conducted on the 33 statements with orthogonal rotation (varimax).

Table 5.1 Extracted factors and their attributes

Factor Number	Factor Name	QOS factors corresponding to the statements
1	Cross-section of roadway design (RD)	No. Of lanes and lane width etc.
2	Arterial operations (AO)	Volume/ Congestion, etc.
3	Intersection Operations (IO)	Timing of signals, etc.
4	Signs and markings (SM)	Quality of pavement markings etc.
5	Maintenance (M)	Pavement quality, etc.
6	Aesthetics (A)	Presence of trees, etc.
7	Road user behaviour (RB)	Illegal manoeuvres, etc.
8	Other facilities (OF)	Planning, etc.

5.3 Regression

From the factor analysis eight factors has been extracted, these eight factors are considered as independent variables and the overall satisfaction is considered as dependent variable. The model summary table shows the R, R^2 values. R value represents the multiple correlation coefficient between the dependent and independent variables. R^2 value is a representation of variability in the outcome that is accounted by the independent variables. In this model its value is 0.709, which tells that all the eight independent variables account for 70.9% of variation in overall satisfaction. The adjusted R^2 value represents how good our model generalizes. The value of Durbin- Watson is 2.163 that is close to 2 showing that it is better and the assumption that the residual terms are not correlated is met.

Table 5.2 Summary of the multiple regression model

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.842	.709	.683	.377	2.163

Table 5.3 shows ANOVA results. F ratio represents ratio of how good the model is compared with respect to how bad the model is. For this model F-value is 27.69 and the significance value is 0.00. The results tells us that the model is significantly improved our ability to predict the outcome variable.

Table 5.3 ANOVA test Results

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	31.549	8	3.944	27.690	.000
Residual	12.961	91	.142		
Total	44.510	99			

B-values indicates the contribution of each independent variable to the model. B -values gives relationship between overall satisfaction and each independent variable. In this model all the predictor values are positive indicating that there is a positive relationship between overall satisfaction and each predictor.

5.4 Cluster Analysis

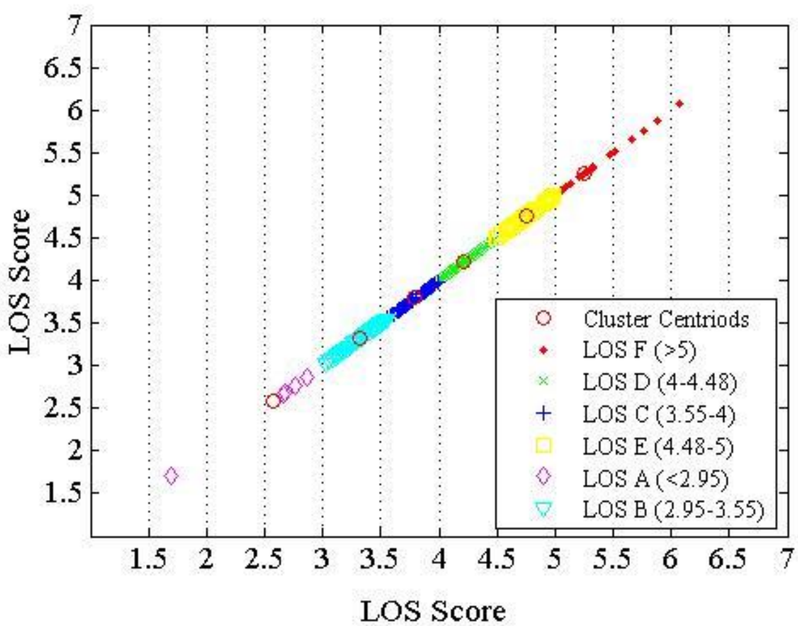

Figure 5.1 Clustering of LOS scores

The LOS scores obtained from the model are clustered into six groups by means of k-means clustering. Silhouette value obtained is 0.7 and so *k*-means clustering gives the best ranges. The ranges of LOS scores for the six groups are as follows.

Table 5.4 Ranges of LOS categories

Range of LOS Score	LOS category

< 2.95	A
2.95 - 3.55	B
3.55 – 4	C
4 - 4.48	D
4.48 – 5	E
>5	F

5.5 Validation of Regression Model

20% of the data is used for validation purpose. A graph is plotted between predicted OS scores and observed OS scores. The slope of the trend line is found to be 43 degrees which is close to 45 degrees indicating that the validation of the model is good.

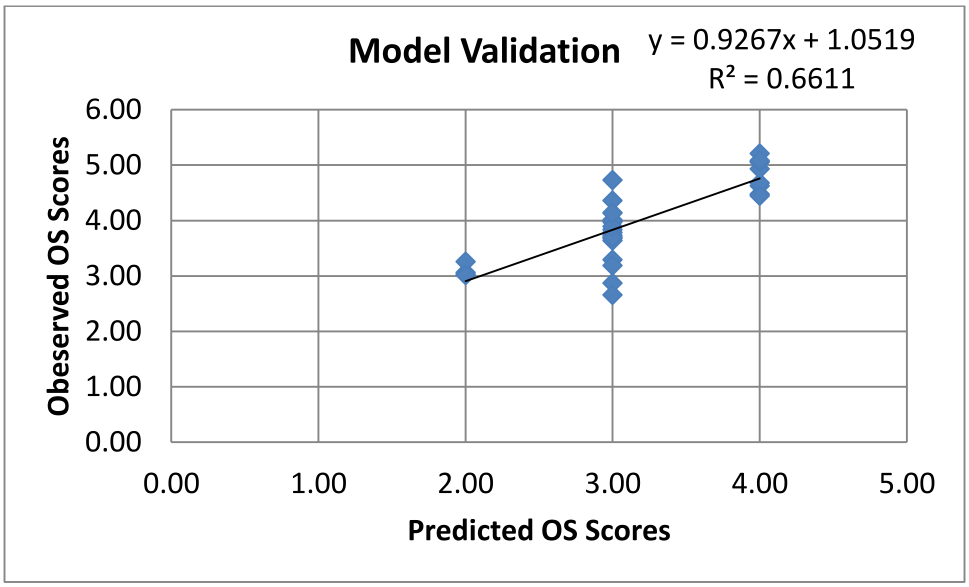

Figure 5.2 Scatter plot of observed vs. predicted OS scores

5.6 Fuzzy Logic

Case Study : Rourkela City

Data was analyzed using fuzzy tool box in MATLAB R2012a. Detailed Fuzzy logic procedure is explained. Fuzzy logic consists of three parts: fuzzification, fuzzy inference and defuzzification.

Fuzzification: Triangular membership functions are assumed for both input and output variables. Each input variable has three subsets namely, good, fair and poor. The output variable has six subsets namely, very good(A), good(B), fair(C), acceptable(D), poor(E) and very poor(F). For the case study the input data RD, TO, TF and RB is fuzzified as shown in the table 5.5

Table 5.5 Fuzzification of input data

Input Variable	Input Data	Fuzzified Category	Membership Grade
RD	4.3	Good	0.12
		Fair	0.88
TO	4.05	Good	0.05
		Fair	0.95
TF	4.11	Good	0.07
		Fair	0.93
RB	3.95	Good	0.06
		Fair	0.94

Fuzzy Inference: Fuzzy inference is based on the If-Then fuzzy rule generation. In the upper level fuzzy inference system there are four inputs and each input variable has three subsets, so 3*3*3*3= 81 rules are to be generated. Some of the fuzzy rules are shown in the table 5.6. For the fuzzified input data it is found that 1, 2, 4, 5, 10, 11, 13, 14, 28, 29, 31, 32, 37, 38, 40 and 41 are involved in this fuzzy inference.

Table 5.6 Fuzzy Rules

No.	Fuzzy Rules
1	If (design is good) and (traffic_operations is good) and (traffic_facilities is good) and (user_behaviour is good) then (user_rating is Very_Good(A))
2	If (design is good) and (traffic_operations is good) and (traffic_facilities is good) and (user_behaviour is fair) then (user_rating is Very_Good(A))
3	If (design is good) and (traffic_operations is good) and (traffic_facilities is good) and (user_behaviour is poor) then (user_rating is Good(B))
4	If (design is good) and (traffic_operations is good) and (traffic_facilities is fair) and (user_behaviour is good) then (user_rating is Good(B))
15	If (design is good) and (traffic_operations is fair) and (traffic_facilities is fair) and (user_behaviour is poor) then (user_rating is Fair(C))
17	If (design is good) and (traffic_operations is fair) and (traffic_facilities is poor) and (user_behaviour is fair) then (user_rating is Fair(C))
27	If (design is good) and (traffic_operations is poor) and (traffic_facilities is poor) and (user_behaviour is poor) then (user_rating is Acceptable(D))
36	If (design is fair) and (traffic_operations is good) and (traffic_facilities is poor) and (user_behaviour is poor) then (user_rating is Acceptable(D))
52	If (design is fair) and (traffic_operations is poor) and (traffic_facilities is poor) and (user_behaviour is good) then (user_rating is Poor(E))
71	If (design is poor) and (traffic_operations is fair) and (traffic_facilities is poor) and (user_behaviour is fair) then (user_rating is Poor(E))
80	If (design is poor) and (traffic_operations is poor) and (traffic_facilities is poor) and (user_behaviour is fair) then (user_rating is Very_Poor(F))
81	If (design is poor) and (traffic operations is poor) and (traffic_facilities is poor) and (user_behaviour is poor) then (user_rating is Very_Poor(F))

Table 5.7 Fuzzy inference using Max-Min Composition Method

Rule No.	Input data				LOS	Max-Min Composition
	RD	TO	TF	RB		
1	Good (0.12)	Good (0.05)	Good (0.07)	Good (0.06)	A	Min (0.12,0.05,0.07,0.06) = 0.05
2	Good (0.12)	Good (0.05)	Good (0.07)	Fair (0.94)	A	Min (0.12,0.05,0.07,0.94) = 0.05
4	Good (0.12)	Good (0.05)	Fair (0.93)	Good (0.06)	B	Min (0.12,0.05,0.93,0.06) = 0.05

5	Good (0.12)	Good (0.05)	Fair (0.93)	Fair (0.94)	B	Min (0.12,0.05,0.93,0.94) = 0.05
10	Good (0.12)	Fair (0.95)	Good (0.07)	Good (0.06)	B	Min (0.12,0.95,0.07,0.06) = 0.06
11	Good (0.12)	Fair (0.95)	Good (0.07)	Fair (0.94)	B	Min (0.12,0.95,0.07,0.94) = 0.07
13	Good (0.12)	Fair (0.95)	Fair (0.93)	Good (0.06)	B	Min (0.12,0.95,0.93,0.06) = 0.06
14	Good (0.12)	Fair (0.95)	Fair (0.93)	Fair (0.94)	C	Min (0.12,0.95,0.93,0.94) = 0.12
41	Fair (0.88)	Fair (0.95)	Fair (0.93)	Fair (0.94)	D	Min (0.88,0.95,0.93,0.94) = 0.88
40	Fair (0.88)	Fair (0.95)	Fair (0.93)	Good (0.06)	C	Min (0.88,0.95,0.93,0.06) = 0.06
38	Fair (0.88)	Fair (0.95)	Good (0.07)	Fair (0.94)	B	Min (0.88,0.95,0.07,0.94) = 0.07
37	Fair (0.88)	Fair (0.95)	Good (0.07)	Good (0.06)	B	Min (0.88,0.95,0.07,0.06) = 0.06
32	Fair (0.88)	Good (0.05)	Fair (0.93)	Fair (0.94)	C	Min (0.88,0.05,0.93,0.94) = 0.05
31	Fair (0.88)	Good (0.05)	Fair (0.93)	Good (0.06)	B	Min (0.88,0.05,0.93,0.94) = 0.05
29	Fair (0.88)	Good (0.05)	Good (0.07)	Fair (0.94)	B	Min (0.88,0.05,0.07,0.94) = 0.05
28	Fair (0.88)	Good (0.05)	Good (0.07)	Good (0.06)	A	Min (0.88,0.05,0.07,0.06) = 0.05
					A : Max (0.05) = 0.05 B : Max (0.05, 0.06, 0.07) = 0.07 C : Max (0.05, 0.06, 0.12) = 0.12 D : Max (0.88) = 0.88	

Note : The number in "( )" is the corresponding membership grade

From the fuzzy inference procedure, the LOS is A (0.05), B (0.07), C (0.12) and D(0.88).

Defuzzification: From the centroid method, the centre of gravity as given in equation (3.4) is calculated and the value of LOS rating is 3.7. This value falls largely into the category of LOS D i.e. Acceptable. Hence, LOS D is designated to Rourkela city. The same procedure is repeated for other cities namely, Visakhapatnam and Thiruvananthapuram. The results are shown in the table 5.8.

Table 5.8 Composite LOS for the three cities

LOS Category	Rourkela	Visakhapatnam	Thiruvananthapuram
A	4.5 %	0 %	0 %
B	6.2 %	6.4 %	5.8 %
C	10.7 %	6.4 %	5.8 %
D	78.6 %	84.4 %	81.7 %
E	0 %	2.8 %	5.8 %
F	0%	0 %	0.9 %
Centre of gravity of LOS Value and corresponding LOS Category	3.7 and LOS D	3.81 and LOS D	3.87 and LOS D

5.7 Model Comparison

LOS categories obtained from both regression and fuzzy models are compared with the actual user perceived LOS. The user-perceived service quality evaluated using fuzzy logic method is in greater agreement with the "actual" perceptions that people hold than the service quality evaluated using the regression method. This methodology offers new insights into perception based LOS and may thus overcome the limitations of conventional delay-based methods to some extent.

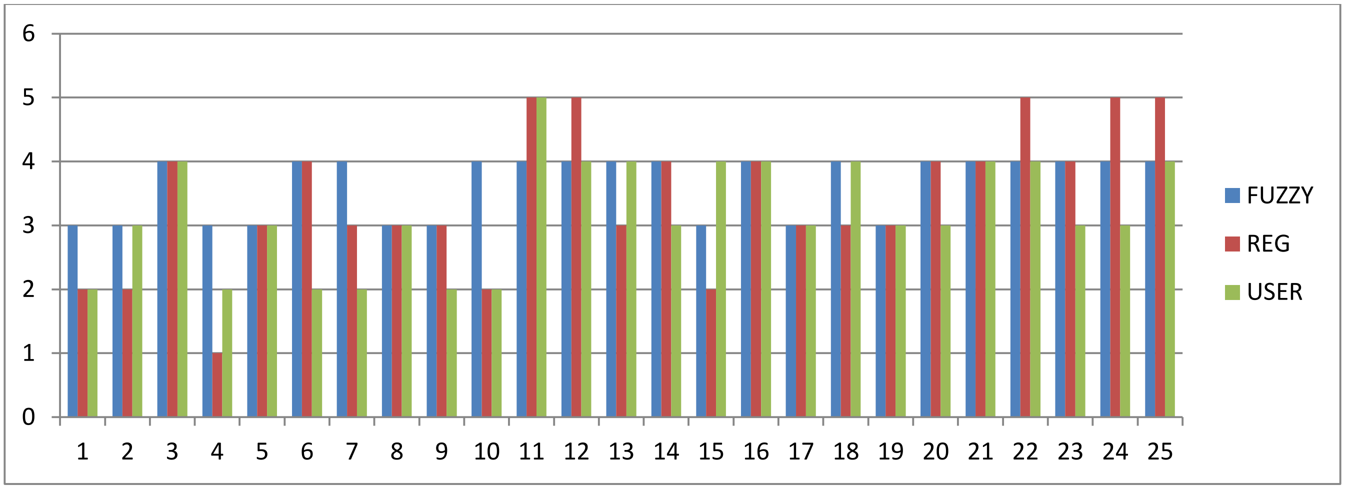

Figure 5.3 Comparison of different models

5.8 Statistical Analysis

Statistical analysis was conducted by taking the user perceived satisfaction level as dependent variable and gender, age group, driving experience (in years) as independent groups. Kruskal-Wallis One- Way ANOVA test is conducted on the independent variables. The 0.05 significance level (i.e., 95% confidence level) was adopted in this statistical analysis.

The effects of independent variables are explained as follows. The mean and standard deviation were respectively, 2.84 and 1.09 for female road users and 3.25 and 1.04 for male road users. From the results it was found that only female users ($\chi^2_{(1)} = 7.4$, $p = 0.007$) were more satisfied compared to the male users. The other two independent variables namely, age group and years of driving experience did not show any significant differences with the overall satisfaction of transportation facilities

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary

Evaluation of LOS by quantitative methods do not include the satisfaction levels of the users. The road user's perspective, their values and their priorities should be considered to evaluate LOS. In the present study a questionnaire is prepared based on various QOS factors affecting the transportation system. Further participants were asked to rate their satisfaction level on a likert scale. About 250 responses were collected for three cities namely, Rourkela, Visakhapatnam and Trivandrum.

The data was analyzed by means of factor analysis and eight factors were extracted and they are cross-section of roadway design, arterial operations, intersection operations, signs and markings, aesthetics, maintenance, road user behavior and other facilities. Considering these eight factors as predictors and overall satisfaction as dependent variable a regression model is developed. Results reveal that coefficients of the predictors are significant and the model gives a good correlation coefficient. 20% of the data is used for model validation purpose. Further ranges of LOS categories were defined by using the *k*-means clustering technique.

Fuzzy logic method is one of the method to evaluate the human decisions. In order to overcome the rule explosion problem hierarchical fuzzy inference system is used in this study. Fuzzification of input data, generation of fuzzy rules and defuzzication to get a crisp value are the steps un fuzzy logic method. Different confidence levels are defined for the three study areas. Comparison of user perceived satisfaction with the regression and fuzzy LOS thresholds is done.

From the statistical analysis it was found that only gender had statistically significant effect on the subject's ratings of overall satisfaction.

6.2 Conclusions

The following conclusions regarding the study of transportation user perception and the developed regression and fuzzy approach were made:

- From the methods discussed in the methodology part, the more feasible method to use in this study is fuzzy logic method. Since the fuzzy technique can analyze uncertain and ambiguous matters that characterize human perceptions.

- For certain types of transportation-related issues, a hierarchical fuzzy inference system is recommended as a more appropriate type of a fuzzy inference system as there will be a rule explosion problem.

- From the model comparison it was found that about 37% of users' perceptions are in agreement with the LOS obtained from the fuzzy model, whereas the regression model showed about 33% agreement with the actual user perceived LOS.

- Results from the fuzzy model showed that Rourkela has A, B, C and D categories of LOS, whereas Visakhapatnam city has B, C, D and E categories of LOS and Thiruvananthapuram has B, C, D, E and F categories of LOS.

- Variations in results obtained from different methods occurred due to the less sample size and also due discrepancy in human perceptions.

- Transportation user perception was affected by many factors including roadway geometry, traffic flow, road user behaviour, and other traffic facilities.

6.3 Future Scope

- This study is conducted in Rourkela city of Odisha state, Visakhapatnam city of Andhra Pradesh state and Thiruvananthapuram of Kerala state. Similar studies can be conducted in other cities as there are significant variation in transportation facilities.
- The present study covers the regions within the city. This type of research can be further extended to the outskirts of the city and how well the city connected with other cities.
- Questionnaire can be improvised by taking the factors that are strongly affecting the users' perception of satisfaction.
- Collected data is insufficient to get accurate results and so there is a need to increase the sample size.
- LOS based on users' perceptions can also be evaluated by other methods like fuzzy weighted average, probit and logit methods.
- This type of study can be used to evaluate perception based LOS at urban arterials, mid block segments and intersections.
- Additional applications to various transportation problems related to user perception should be conducted. Through these applications, developed methods will be extended by addressing current limitations and problems.

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